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Feasibility Study of the Effectiveness of Drilling Mud as a Plugging Agent in Abandoned Wells

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16. ABSTRACT

The main objective of this feasibility study was to test the hypothesis that properly plugged wells are effectively sealed by drilling mud. While achieving such an objective, knowledge of the dynamics of building mud cake on the wellbore-face is obtained, as well as comprehension of changes that occur in drilling mud from the time it is placed in a well until it reaches equilibrium.

A system was developed to simulate (a) building mud cake in a borehole, (b) plugging the well, and (c) injecting salt water into a nearby well, with concomitant migration of salt water into the plugged well. The system "duplicates" reservoir pressures, mud pressures, and reservoir-formation characteristics that develop while mud cake is built, as in drilling a well. Salt-water injection is simulated, to monitor any fluid migration through the reservoir.

A 2100-ft. well and ancillary equipment was constructed to permit controlled measurement and variation of simulated depth, porosity and permeability of reservoir rock, fluid composition, fluid pressure, injection pressure, and mud properties. Data can be recorded continuously by computer.

The in-place system provides for extensive testing of the many variables that influence effective plugging of boreholes with drilling mud.

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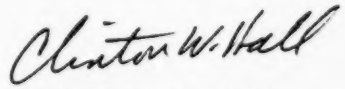
FOREWORD

EPA is charged by Congress to protect the Nation's land, air and water systems. Under a mandate of national environmental laws focused on air and water quality, solid waste management and the control of toxic substances, pesticides, noise and radiation, the Agency strives to formulate and implement actions which lead to a compatible balance between human activities and the ability of natural systems to support and nurture life.

The Robert S. Kerr Environmental Research Laboratory is the Agency's center of expertise for investigation of the soil and subsurface environment. Personnel at the laboratory are responsible for management of research programs to: (a) determine the fate, transport and transformation rates of pollutants in the soil, the unsaturated and the saturated zones of the subsurface environment; (b) define the processes to be used in characterizing the soil and subsurface environment as a receptor of pollutants; (c) develop techniques for predicting the effect of pollutants on ground water, soil, and indigenous organisms; and (d) define and demonstrate the applicability and limitations of using natural processes, indigenous to the soil and subsurface environment, for the protection of this resource.

This report presents the results of research on methods for determining the effectiveness of drilling mud as a plugging agent in abandoned wells to assure the protection of human health and the environment.



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ABSTRACT

The Hazardous and Solid Waste Amendment of 1984 requires the Environmental Protection Agency to assess environmental suitability of liquid-waste injection into subsurface rock. Accordingly, the reaction among injected wastes, reservoirs, and original formation fluids is under evaluation.

The main objective of the feasibility study described here was to test the hypothesis that properly plugged wells are effectively sealed by drilling mud. While achieving such an objective, knowledge of the dynamics of building mud cake on the wellbore-face is obtained, as well as comprehension of changes that occur in drilling mud from the time it is placed in a well until it reaches equilibrium.

A system was developed to simulate (a) building mud cake in a borehole, (b) plugging the well, and (c) injecting salt water in a nearby well, with concomitant migration of salt water into the plugged well. The system "duplicates" reservoir pressures, mud pressures, and reservoir-formation characteristics that develop while mud cake is built, as in drilling a well. Salt-water injection is simulated, to monitor any fluid migration through the reservoir.

A 2100-ft. well and ancillary equipment permit controlled variation of simulated depth, porosity and permeability of reservoir rock, fluid composition, fluid pressure, injection pressure, and mud properties. Data can be recorded continuously by computer.

The synthetic-sandstone reservoir is cylindrical, 3 ft. in diameter and 2 ft. thick. It has porosity and permeability similar to those of several natural reservoirs.

Pressures commensurate with those in 5000-ft.-deep wells were to be measured; associated differential pressures were required. A system developed to measure differential mud pressures includes undiminished pressure-transmittal by diaphragm-interface.

Also, a high-pressure, low-flow-rate, high-accuracy flow meter system was developed to monitor the slightest amount of fluid movement. Flow meters were developed to measure (a) fluid from the reservoir, (b) mud-column flow from above the reservoir, and salt water being injected.

An in-place system provides for extensive testing of the many variables that influence effective plugging of boreholes.

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SECTION 1

INTRODUCTION

The Environmental Protection Agency is required by the Hazardous and Solid Waste Amendment of 1984 to assess the environmental suitability of injection of liquid wastes into subsurface formations. The Agency's approach to this matter is composed of three general activities: (1) to evaluate the construction of injection wells and the capability for monitoring them, in order to detect failures, (2) to assess the relationship among the rock-stratigraphic units, the fluids injected, and the integrity of the bounding confining beds, and (3) to evaluate the reaction among the injected waste, the formation, and the formation fluids.

The primary objective of the research described here is to test this hypothesis: Drilling mud in abandoned, properly plugged wells effectively seals the borehole. Therefore, if fluids injected into reservoirs at depth were to migrate up the boreholes of properly plugged wells, filter cake nevertheless would prevent passage of these fluids into other reservoirs. The alternate hypotheses need no elaboration.

A 2100-ft. well and ancillary facilities are described in pages that follow. This system permits controlled variation of simulated down-hole conditions, including depth, porosity and permeability of reservoirs, compositions of fluids, pressures of fluids, injection pressures, and properties of plugging agents. Instrumentation was designed and assembled, or manufactured, in order to test the feasibility of monitoring variation in pressures and rates of flow of fluids, under several regimes of injection. Computer software was written for continuous reception and recording of data. Methods were developed for construction of an artificial sandstone reservoir; porosity and permeability of this reservoir and some actual reservoirs are similar.

SECTION 2

CONCLUSIONS

1. Feasibility of designing and equipping a shallow well for the purpose of the experiment has been demonstrated.

2. A technique and hardware were developed to measure down-hole pressure gradients accurately.

3. A multiplexer to transfer data from down-hole to the surface was designed and built, as were a computer board and software, to process and store data.

4. Other equipment designed, built and developed included a diaphragm-seal housing assembly, a temperature-sensor circuit, a flow-meter and flow-control system (for uncommonly low rates of flow at high pressure), and a mud-maintenance, mud-flow network and control system.

5. An artificial reservoir with lithic properties, porosity and permeability similar to actual injection-formations was constructed, complete with housing and attendant instrumentation. After initial guidance by Halliburton Company, techniques were developed for composing, mixing, emplacing and consolidating reservoir material, to obtain porosity and permeability within specified limits. Moreover, methods were developed to isolate and measure radial flow through the large artificial reservoir.

6. A cased-well system, designed and constructed, allows simulation of conditions below the artificial reservoir of depths as great as 2000 ft., and controlled injection of fluids at depths of 100 to 2000 ft. The facility could, and should, be used to define the entire array of critical conditions of mud-plugging. Also, it should be employed for experimentation and development of new products and techniques for protecting fresh-water aquifers.

SECTION 3

RECOMMENDATIONS

Developments of a unique facility are essentially complete. The facility will allow investigation of many phenomena associated with wells, reservoirs, fluids and methods of measurement. To utilize this facility for tests to include but not be limited to the following topics is recommended.

1. Test the existent artificial reservoir, despite the fact that it seems to be fractured. Build mud cake on it and determine the amount of mud and the invasion required to build the mud cake. Test the adequacy of the mud cake to resist invasion under injection at various pressures.

2. Complete a series of tests to determine the performance-envelope of parameters that could affect the plugging and protection of a rock formation. This would include various mud properties, various injection-fluid properties, various reservoir porosity and permeability values (including fractured layers), various combinations of injection-zone and protected-zone depths and injection pressures.

3. Develop a tool and associated instrumentation which could be inserted into an abandoned, plugged well and determine the in-place mud properties. These properties, in conjunction with the results of Recommendations 1, above, could provide a method to estimate the adequacy of fluids in plugged wells.

4. Investigate additives that could enhance the mud-plugging of high-porosity zones and fractured zones. These could be evaluated during the mud-cake build-up period and then during injection of disposable fluids.

5. Determine the effect of leaching in mud-plugged wells and the conditions that allow the phenomenon to occur.

SECTION 4

TEST FACILITY DESIGN, DEVELOPMENT AND FUNCTION

INTRODUCTION

DESCRIPTION OF FACILITY

The facility is designed for testing under conditions that simulate a well plugged with mud, for abandonment. A zone in the upper region of the hypothetical well is an underground source of drinking water (protected zone, Figure 1), and the intention is to not contaminate it. Below the fresh-water-bearing formation is a formation used for injection (Figure 1), pressurized by disposal of salt water into a nearby well. Pressure is translated through the injection zone to the abandoned well. Therefore, a potential exists for the salt water to migrate up the wellbore and invade the underground source of drinking water. The purpose of the testing design is to determine the array of conditions that could allow invasion of the zone of drinking water to occur.

The testing facility is divided into four basic areas, which are associated with zones in a plugged and abandoned well, shown diagrammatically in Figure 1. These areas are dedicated to study of the wellbore above the reservoir being protected (region 1), the protected reservoir and wellbore (region 2), the wellbore below the protected reservoir, and the salt-water disposal reservoir (region 3), and the overall part of the facility that simulates drilling the well and building mud cake on the wall of the wellbore. Regions 1 and 2 shown in Figure 1 are simulated by facilities located above ground level, whereas region 3 is an actual well, 2100 ft. deep. The part of the facility that simulates building of mud cake is also above ground.

In the following sections, the various components or assemblies that combine to form the facility are discussed. Included is a brief description of each component, statement of its purpose, salient design features, description of its interaction or connection with other components or assemblies, controlling features, associated instrumentation and the type of data produced.

TOTAL-FACILITY SCHEMATIC DIAGRAM

Figure 2 is a plan view of the facility. Individual systems are required to obtain quantitative data on results of injecting salt water into a reservoir and the effects of